Adjustable AF Notch Filters

high Q factors in the audio range

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Add two op-amps to a Wien-Robinson bridge and we can construct a notch filter whose centre frequency can be set using a single resistor. This is a significant advantage when compared with the commonly-used double-T network.

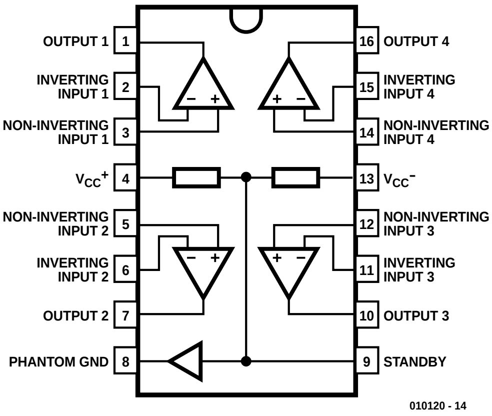

Figure 1. This quad rail-to-rail op-amp also offers a buffered virtual earth output.

The notch filter described in this article employs the ST Microelectronics type **TS925 quad operational amplifier**. This part offers rail-to-rail (ground to U_S) operation on both inputs and outputs and has the additional advantage that an internal voltage divider and buffer IC1.E generate a virtual ground at a potential U_S / 2 (**Figure 1**).

The circuit of **Figure 2** shows a modified Wien-Robinson bridge with resonant frequency f_o. IC1.B, together with C2, C4, R3, R6, R7 and R8 realise the complex branch of the bridge, while R1+R2, R5 and IC1.C form the real branch. Here, IC1.C operates as an inverting amplifier whose gain can be adjusted via R1 in the range 0.93 to 1.07 to obtain the best rejection of signals at frequency f_o. In the prototype a ratio (u_{o_eff} / u_{i_eff}) of better than –55 dB was achieved. With input signals of a frequency $f_e << f_o$, C2 and C4 have

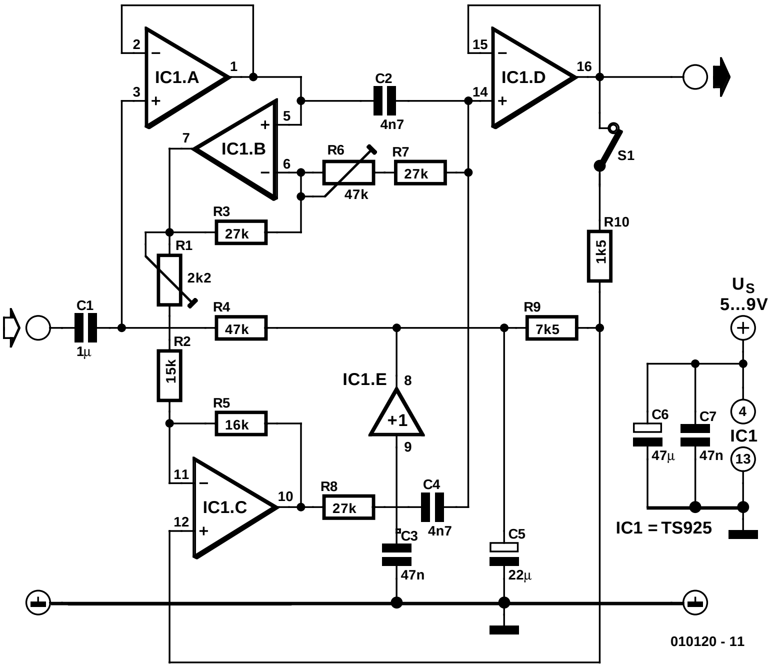

Figure 2. Simple adjustable notch filter.

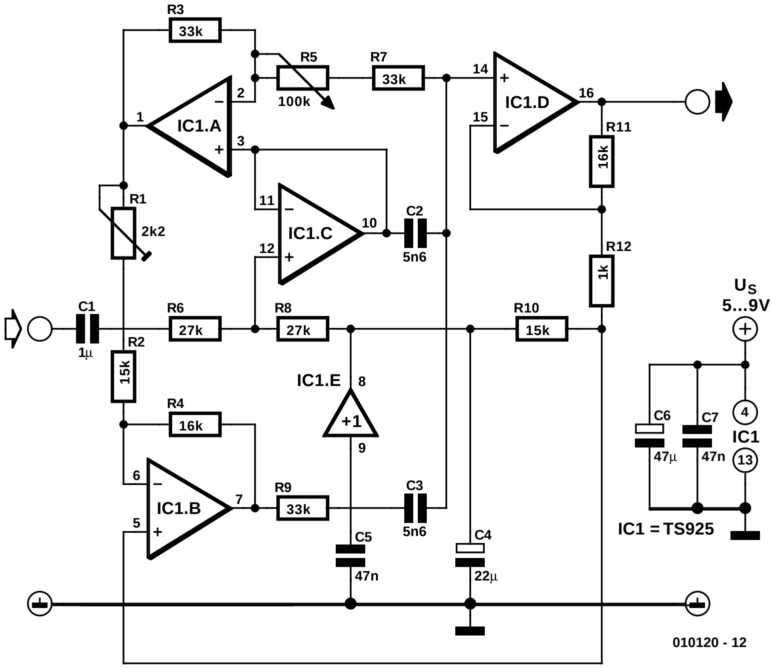

Figure 3. Notch filter suitable for higher input voltages.

practically no effect and the circuit works as a voltage follower with unity gain. In the case $f_i >> f_o$, C2 and C4 act as short-circuits, and again the desired voltage follower operation is obtained. With the requirement that R3 = R8, C2 = C4, and R1+R2 = R5, we can derive the equation for the centre frequency of the extended Wien-Robinson bridge circuit around IC1.B and IC1.C:

$$f_o = 1 / [2\pi\ R8\ \ C4 \sqrt{(R6 + R7) / R3}]$$

It makes essentially no difference whether (R6+R7)/R3 is greater than or less than 1. (R6+R7)/R3 ≥ 1 is, however, more appropriate from the point of view of the maximum permissible filter input voltage. Then, independent of the position of the adjustment potentiometer R6, the peak output voltages of IC1.B and IC1.C are at most $\pm\hat{u}_{IC1.B} = \pm\hat{u}_{IC1.C} \leq \pm 2\hat{u}_e$, assuming the input signal to be a sine wave. With the rail-to-rail op-amps used here and with (R6+R7) / R3 ≥ 1 we can thus allow sinewave inputs with amplitudes of up to $\pm\hat{u}_i = U_S / 4$, or in other words $u_{i\_eff} = U_S / 4\sqrt{2}$.

The ratio (R6+R7)/R3 affects the Q factor Q_S of the notch filter. With S1 open and R6+R7 = R3 we can achieve a Q factor of 0.5, which is the value which can be derived for the basic Wien-Robinson bridge arrangement. The Q factor can be increased by feeding back a fraction of the output voltage to the non-inverting input of IC1.C. For Q_S we then have:

$$Q_S = R9+R10 / [2\ R10 \sqrt{(R6+R7) / R3}]$$

With R9=0 Ω or with S1 open the feedback is disabled. The filter then has Q factor $Q_S = 1/2 \sqrt{(R6+R7)/R3}$. On the other hand, with R10=0 Ω the Q factor becomes infinite: the arrangement becomes unstable and oscillates. The prototype values were calculated for $u_{i\_eff} \leq 0.8$ V at $U_S = 5$ V and for a centre frequency range of 0.76 kHz to 1.25 kHz.

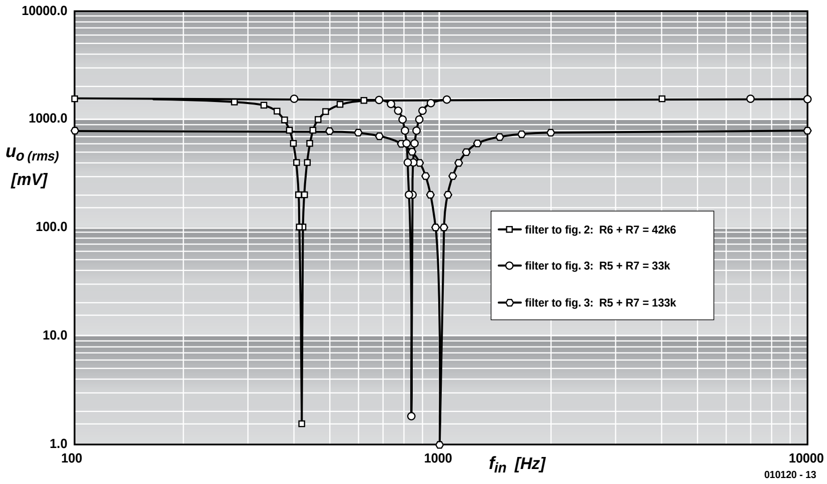

Figure 4. Frequency response of the notch filter.

An alternative arrangement

The alternative arrangement shown in **Figure 3** allows a pass-band gain of 1 for sinusoidal input signals with $\pm\hat{u}_i = U_S / 2$. This is achieved using an input voltage divider (R6 and R8), whose attenuation is compensated for by op-amp IC1.D with a gain of 2. With C2=C3, R3=R9 and R1+R2=R4 we have the following expressions for the centre frequency and Q factor of the notch filter:

$$f_o = 1 / [2\pi\ R9\ \ C3 \sqrt{(R5+R7) / R3}]$$

$$Q_S = (R10+R12) / [2\ \ R12\ \sqrt{(R5+R7) / R3}]$$

The component values shown are suitable for sinusoidal inputs with $u_{i\_eff} \leq U_S / \sqrt{8}$, for U_S in the range 5 V to 9 V, and for a centre frequency range of 420 Hz to 834 Hz. As this is adjusted via variable resistor R5, the Q-factor of the filter also varies, as can be seen from the transfer characteristics plotted in **Figure 4**. It is interesting to note that the bandwidth of the filter $B_S = f_o / Q_S$ is independent of this adjustment:

$$B_S = R12 / [\pi\ R9\ C3\ (R10+R12)]$$

At both f_o = 420 Hz and f_o = 834 Hz a bandwidth of 110 Hz is measured; the calculated value is 108 Hz, showing good agreement between theory and practice.

(010220-1)